Skin Research and Technology 2016; 22: 513–518
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doi: 10.1111/srt.12296

Skin Research and Technology

Three-dimensional imaging for volume measurement of hypertrophic and keloid scars, reliability of a previously validated simplified technique in clinical setting

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Introduction: Evidence behind many of the current treatments in hypertrophic and keloid scars remains limited. Current objective methods to assess efficacy and provide follow-up can be complex and are not easily applied in clinical setting. The aim of this study was to assess reliability of a recently validated simplified technique for volume measurement in clinical practice.
Methods: Volume measurement of 28 hypertrophic and keloid scars was conducted in 22 consecutive patients, using a three-dimensional stereophotogrammetry. Intra- and inter-rater reliability was assessed by the intraclass correlation coefficient (ICC) and the coefficient of variation (CV). The measurement error was expressed as limits of agreement (LoA).
Results: The simplified method for three-dimensional volume measurement showed good intra-rater reliability with an ICC of 0.997 and a CV of 7.3%, and a good inter-rater reliability with an ICC of 0.999 and a CV of 5.7%. The plot of the differences and LoA showed near-perfect agreement between observers.
Conclusion: Objective evaluation of scar volume using the simplified three-dimensional measurement technique may complement subjective scoring and improve the ability to quantitatively compare the response to therapeutic methods.

Key words: keloid – three-dimensional imaging – reliability – scar volume

Accepted for publication 20 April 2016

Hypertrophic and keloid scars are abnormal wound responses in predisposed individuals, which represent a connective tissue response to trauma, surgery, or burns (1). Scar tissue can be distinguished from healthy skin by an aberrant color, loss of elasticity, and contraction or expansion of the surface area. Patients frequently endure functional, cosmetic, and psychological consequences (2, 3). Effective treatment and prevention of these pathological scars is important, though evidence behind many of the current treatments is limited (1).

To assess treatment response, and compare efficacy of different treatment modalities, a reliable and accurate assessment tool is required (4). Many of the scar assessment tools in current use are semi-quantitative observer based scales such as the Vancouver Scar Scale (5), and more recently, the Patient and Observer Scar Assessment Scale (6).

An advantage of objective assessment is that scars can be compared quantitatively. Therefore, these tools are usually statistically superior to a scar scale (i.e. less subject to observer bias) (7).

Objective methods of assessment like direct casting and the use of high-frequency ultrasound have some considerable limitations. Direct casting can introduce errors in measurement due to skin deformation during molding, while ultrasound only assesses cross-sectional depth, not the volume (8, 9).

In 2007 Taylor et al. (10) reported the use of a non-contact 3D digitizer to measure the volume of a keloid scar. They showed a significant positive correlation between the volume of a keloid scar and the clinical physical severity according to the semi-quantitative Manchester Scar Scale (11). Ardehali et al. (12) found a near-perfect correspondence between actual volumes of simulated scars and those obtained using three-dimensional imaging. In 2015, Stekelenburg et al. (13) found three-dimensional stereophotogrammetry to be suitable for the use in clinical research, but not for the follow-up of the individual patient due to too large absolute measurement errors.

Recently, a simplified three-dimensional volume measurement technique was validated for simulated keloid scars (14). Thirty-three scars were simulated using deformable modeling compound with variable volumes (a mean volume of 2.884 cc), which were applied to the sternum of subjects. The use of a flattened surface for three-dimensional volume measurement makes this technique simplified and more fit to use in clinical practice.

This study was designed to assess the reliability of this recently validated simplified technique in clinical practice. Furthermore, we aim to describe possible application of this method for objective follow-up of hypertrophic and keloid scars.

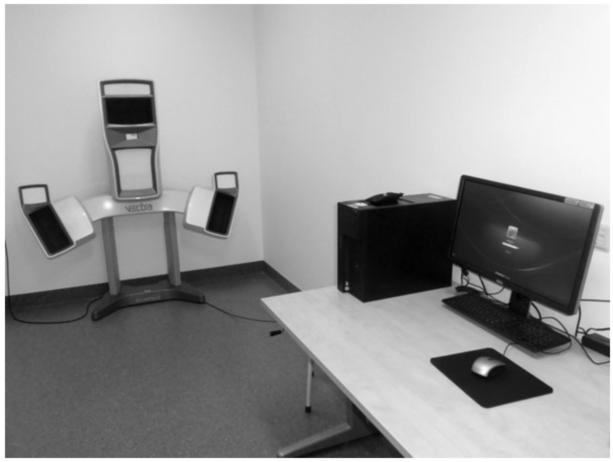

Fig. 1. Vectra XT 3D imaging system.

Methods

Subjects

Subjects were recruited from the Department of Plastic, Reconstructive, and Hand Surgery of the University Medical Center in Maastricht, the Netherlands. Twenty-eight hypertrophic and keloid scars were included from 22 consecutive patients. Causes of the scar ranged from burn, surgery, trauma to chickenpox, or acne. Other demographic and scar characteristics i.e. gender, age, scar type, location of the scar, and cause of the scar, were collected. Of all hypertrophic and keloid scars at least one, preferably two, three-dimensional images had to be available.

Three-dimensional imaging system

Three-dimensional capture of hypertrophic and keloid scars was conducted using the Vectra XT 3D imaging system (Canfield Imaging Systems, Fairfield, NJ, USA). The camera determines points in three dimensions by triangulating position of six color digital cameras. A three-dimensional surface image is generated through the principle of passive stereophotogrammetry, where the texture of the skin is used to determine geometry (Fig. 1).

Volume measurement was done using Mirror Analysis 3D software (Canfield Imaging Systems). The hypertrophic or keloid scar was selected from the three-dimensional image by pointing out the boundaries and an enclosed surface was created. Volume was measured using the option 'closed volume measurement' (Fig. 2) (14).

Study design

Available images were retrospectively collected from April 2013 until October 2014. Volume measurement was performed based on the three-dimensional images.

Several indicators were used to determine intra-rater and inter-rater reliability of the 3D volume measurements; the intraclass correlation coefficient (ICC) was used to compare variability due to measurement error with the variability between subjects. An ICC of $\geq$0.90 was considered to be acceptable for use in clinical practice. To assess the extent of variability in measurements in relation to the mean volume that was measured, the coefficient of variation (CV) was used. A CV of $\leq$10% was considered a requirement for reliable results. The agreement between observers for measuring scar volume was displayed using Bland–Altman plots and calculating their limits of agreement (LoA). Data were analyzed using SPSS 20.0 software (SPSS Inc., Chicago, IL, USA).

The study was approved by the Medical Ethical Committee of Maastricht University Medical Center.

Results

Subject characteristics

A total of 22 patients with a consecutive 28 scars were enrolled in this study. The mean

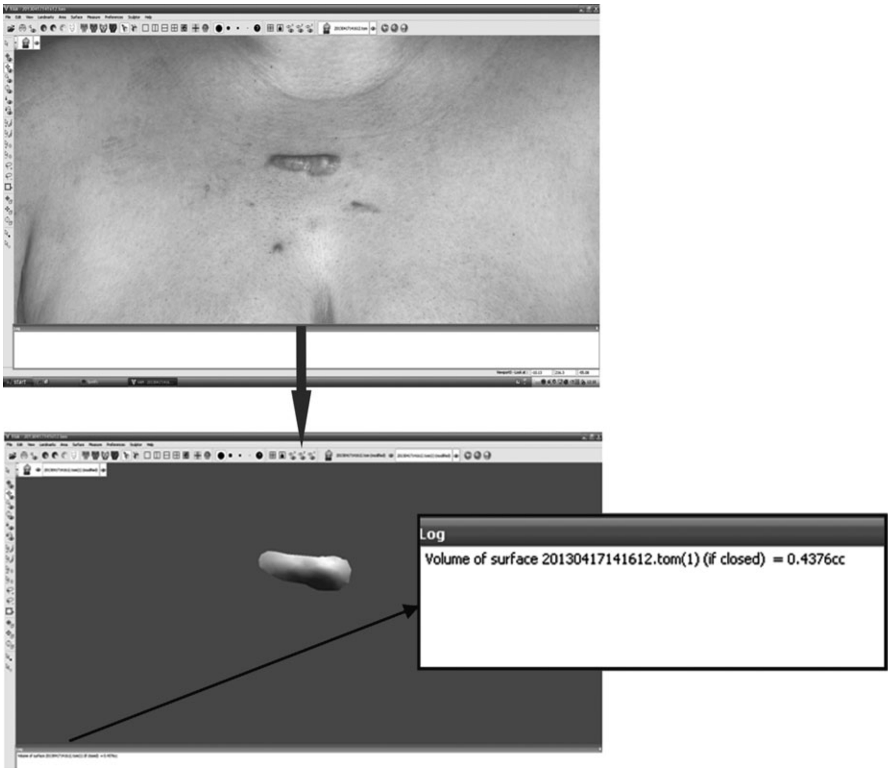

Fig. 2. Volume measurement using Mirror Analysis 3D software.

age was 27 years (range 9–69). The most common cause of the scar was surgery, with a 46%. Subject characteristics are summarized in Table 1.

TABLE 1. Subject characteristics

Characteristics	Value
Patients, *n*	22
Scars, *n*	28
Gender, *n*	
Male	10
Female	12
Age, years	
Mean	27
Minimum	9
Maximum	69
Scar type, *n*	
Hypertrophic	13 (46%)
Keloid	15 (54%)
Location of the scar, *n*	
Sternum	11 (39%)
Neck/lower jaw	5 (13%)
Other (e.g. back, thorax, knee)	12 (43%)
Cause of the scar, *n*	
Burn	2 (7%)
Surgery	13 (46%)
Trauma	4 (14%)
Acne/chickenpox	6 (21%)
Unknown	3 (11%)

Reliability

Intra-rater reliability

The intra-rater reliability was assessed by comparing the results of three 3D volume measurements for 28 hypertrophic or keloid scars by the main investigator. An ICC of 0.997 with 95% CI (0.994–0.998) was obtained for the intra-rater reliability. CV had a mean of 7.3% with a minimum of 0.8 and a maximum of 28.7% (SD = 5.6).

Inter-rater reliability

The inter-rater reliability was assessed with 3D volume measurements of two different observers. The main investigator executed all the measurements and the second observer, who was blinded to the results of the main investigator, executed measurements of fifteen randomly picked hypertrophic- and keloid scars. An ICC of 0.999 with a 95% CI (0.997–1.000) was obtained for the inter-rater reliability. CV had a mean of 5.7% with a minimum of 1.6 and a maximum of 12.1% (SD = 3.7).

A strong agreement between both observers was seen in the Bland–Altman plot. The LoA were mean difference $\pm$ 1.96 $\times$ SD difference. A plot that compared their measurements showed a near-perfect correspondence (Fig. 3a and 3b).

Discussion

Various scar assessment tools have been proposed and tested for their feasibility. Many of these scales provide a measure of overall scar quality, but tend to be subjective and observer dependent (15, 16). An objective tool for measuring scar volume is important to enable comparison of treatment regimens and to provide objective follow-up. Current objective methods, which include direct casting and high-frequency ultrasound, can be complex and are not easily applied in clinical setting (8, 9). The use of a three-dimensional imaging system was previously studied and showed promising results. However, these techniques require

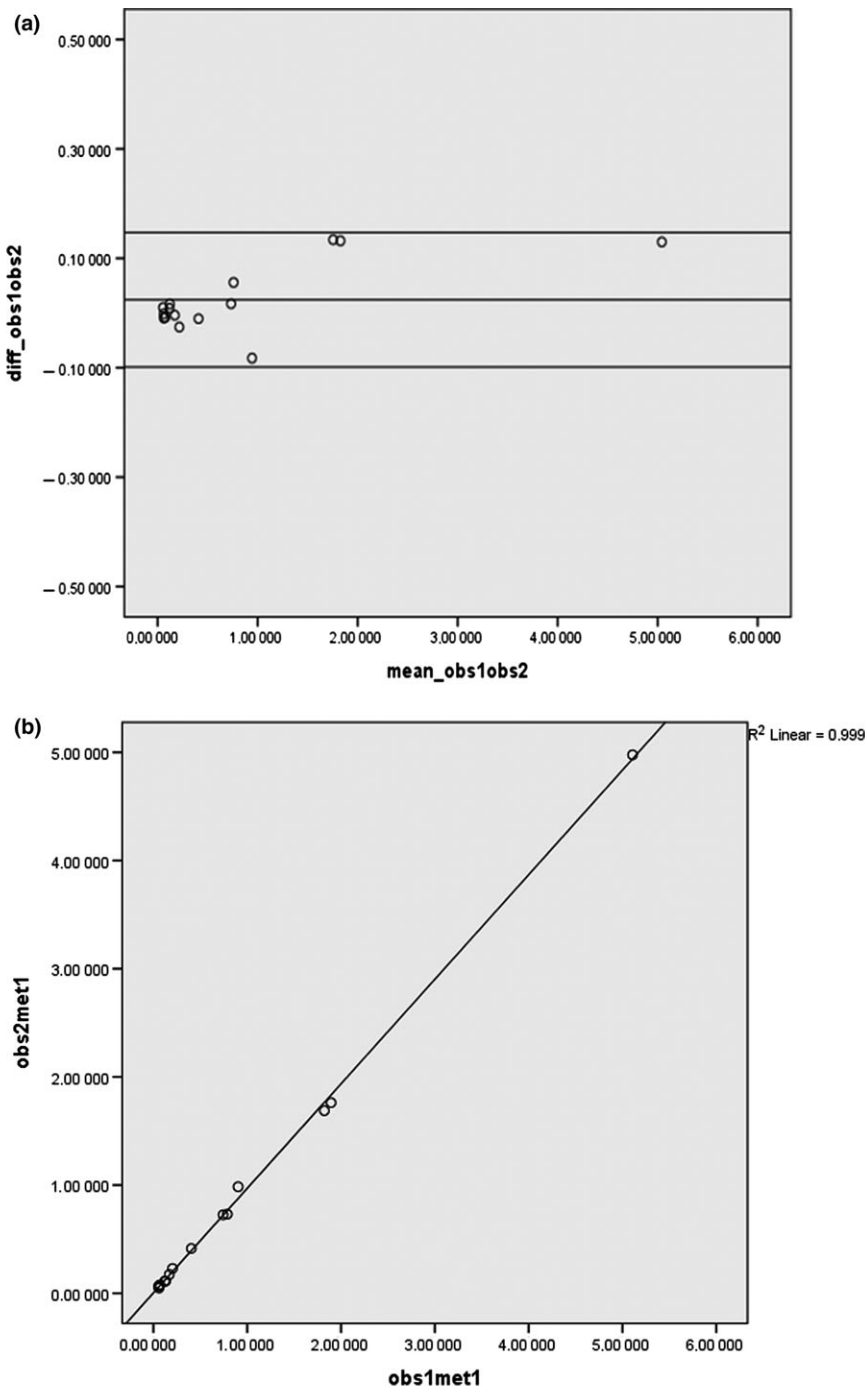

Fig. 3. (a) Bland–Altman plot of the volume difference between the two observers vs. the mean volume of the two Observers. (b) A plot of measurements by observer two vs. measurements of observer one.

experienced examiners and the process of computerized digital reconstruction for data analysis can take up to ten minutes (10, 12).

A new simplified technique using the Vectra 3D imaging system for scar assessment was analyzed, its validity was confirmed in a previous study (14). The high ICC's and low CV's found in this study indicate that the method is extremely reliable. An additional analysis was performed by presenting the LoA, this analysis showed a strong agreement between the two observers.

Three-dimensional images were captured at a standardized manner and volumes were measured using a relatively easy method. It should be noted that the reliability is highly dependent on the heterogeneity of the study population, since it is easier to distinguish between scars with a wide range of volumes than scars with small volume differences. However, the study population was a good representation of the patients as seen in clinical practice, which means that the values for ICC en CV are representative.

The Vectra 3D imaging system is very user-friendly; the procedure of taking a picture, processing the data, and measuring the volume takes approximately five minutes. Patient discomfort is minimal because of the non-contact method. The simplified technique for measuring volume, using the boundaries of a scar to create an enclosed surface, is more fit to use in clinical practice. Despite these practical benefits, knowledge of limitations is also important for an optimal application. The Vectra 3D imaging equipment and software are valuable, which may be prohibitive for smaller medical centers. The camera is a large and heavy object, which is not very deportable. Furthermore, hair within the area of interest can interfere with three-dimensional reconstruction by causing artifacts. This makes volume measurement of a scar in this area not reliable.

Conclusion

Qualitative assessment of scars is deemed to be useful, different parameters of subjective evaluation may result in an overall impression of the scar. For hypertrophic scars and keloids, the most characteristic and comprehensive feature seems to be volume. Objective evaluation of scar volume using the simplified three-dimensional measurement technique was previously found to be valid and reliable when using deformable modeling compound to simulate keloids (14). This study showed high reliability in a clinical setting. Objective evaluation of scar volume using the simplified three-dimensional measurement technique may complement subjective scoring and improve the ability to quantitatively compare the response to therapeutic methods. However, ideally large-scale prospective studies are needed to further explore the use of the technique in clinical practice to allow monitoring of an individual patient.

Funding

None.

Conflicts of interest

None.

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Supporting Information

Additional Supporting Information may be found in the online version of this article.

Video S1. Keloid scar volume measurement using the Vectra 3D camera (Maastricht technique).